

Effects of Salinity and Temperature on Survival and Development of Larval Atlantic Menhaden, *Brevoortia tyrannus*

INTRODUCTION

Atlantic menhaden are subject to a wide range of salinity during early stages of development. Most evidence indicates that this species spawns principally along the middle and south Atlantic Coast of the United States during the winter, some distance offshore (Reintjes, 1961; Massmann, Norcross, and Joseph, 1962). After hatching at sea, larvae enter the estuaries and move into the upper tidal areas of tributary streams where they develop into juveniles (June and Chamberlin, 1959). From the time they hatch until they reach the nursery areas, larvae run the gamut of salinities from about 35‰ to about 1‰ (Reintjes and Pacheco, 1966).

Water-development projects and pollution are becoming more prevalent as the human population grows. For example, dams that will effect large masses of water in estuaries on the Atlantic and Gulf coasts of the United States are under consideration. These structures will probably reduce the nursery areas accessible to menhaden larvae and may reduce the numbers of menhaden. Therefore, it is important to learn what happens to larvae that are prevented from reaching a low-salinity environment.

Laboratory experiments were designed to ascertain the effects of salinity and low temperature on the survival and growth of menhaden larvae. During 1964, experiments at Beaufort, North Carolina, yielded information on the temperature tolerance of Atlantic menhaden larvae at a fixed salinity (Lewis, 1965). The study reported here consisted of two experiments. The objective of the first was to determine the effect of various levels of salinity at low temperatures on the survival of menhaden larvae, those of the second were to determine (1) if larval menhaden will transform into normal juveniles in salinities

of 15‰ and greater, and (2) if they transform, it is important to know what effect exposure to these salinities has on their development.

An anchored net, 12 m long, 2.5 m deep, and constructed of 3-mm-diameter mesh with a large bag leading into a floating box, was used during daylight to trap and hold larvae for the experiments. More specimens were obtained in less time than in 1964, when larvae were collected at night on flood tides with a plankton net that funneled into a similar box.

COMBINED EFFECTS OF SALINITY AND LOW TEMPERATURE

Equipment and procedures.—The holding, acclimation, and test tanks were the same as used in 1964 (Lewis, 1965), except that sea water was filtered through synthetic sponges rather than glass wool and marble chips. Temperature in the acclimation tank and in the three fiber-glass test chambers was controlled by a Thermistemp and thermistor probe made by the Yellow Springs Instrument Company.¹ Use of this equipment made possible the rapid adjustment of temperatures for each new test. Salinity was measured by a hydrometer and adjusted to the desired concentration by adding distilled water. Well water was used for the tests in fresh water. Dissolved oxygen, checked periodically in all test containers, ranged from 80% to 95% saturation. Larvae were fed 1- and 2-day-old nauplii of *Artemia salina* daily. All larvae fed, except those under stress. Larvae were tested at temperatures of 2 to 6 C (by 1-degree intervals) and at salinities of 0 to 30‰ (by 5‰ intervals). Prior to each test they were acclimated at temperatures of either 10 or 15 C and salinity of 25 to 30‰ for 102 ± 84 hours. At this stage of life history menhaden appear to acclimate in but a few hours as they feed well and no mortality occurs. Limited facilities,

¹ The Bureau of Commercial Fisheries neither recommends nor disapproves the products referred to in this paper.

TABLE 1.—Number of hours to 50% mortality of menhaden larvae acclimated at 10 C and held at different combinations of temperature and salinity

Test temperature Celsius	Salinity ‰						
	0	5	10	15	20	25	30
2	4.2	14.2	27.5	34.0	25.0	21.5	15.2
3	4.2	33.0	59.0	77.6	53.2	40.0	26.5
4	7.0	96.0	96.0	96.0	96.0	96.0	35.0
5	7.8	96.0	96.0	96.0	96.0	96.0	96.0
6	13.0	96.0	96.0	96.0	96.0	96.0	96.0

tight scheduling of experiments, and ready availability of material caused wide variation in acclimation time.

Results.—As in the 1964 tests, when larvae entered a chill coma they lost their equilibrium, floated, and twitched erratically. At salinities of 5‰ and less some larvae died with their mouths wide open, indicating a convulsive death; all turned stiff and milky-colored immediately after dying.

Results of the 10 C acclimation series (Table 1) indicated that under natural conditions larvae can be expected to survive for approximately 1 day in water of 2 C and 10 to 25‰ salinity, and 2 or 3 days at 3 C and 10 to 20‰ salinity. Larvae probably would live for only a few hours at temperatures of 6 C and below in fresh water (0‰), whereas the probability of survival generally would be good at temperatures of 4 C and above, and salinities between 5 and 30‰.

Larvae acclimated at 15 C and held at 2 C survived almost 2 days in a salinity of 10‰, and 1 day in 15‰ (Table 2). Survival at 2 C was less than 1 day in other salinities tested. At 3 C, larvae survived approximately 2 days in salinities between 5 and 20‰. As in the 10 C acclimation series, larvae survived only a few hours in 0‰ salinity. In both acclimation series, the lower and upper limits of salinity tolerance increased with increasing temperature.

Bishai (1961) found that newly hatched larvae of herring, *Clupea harengus*, can live at salinities as low as 2.5‰, and that they live longer in salinities of 10 to 15‰ than in higher or lower salinities. In general, these findings agree with the results of the present experiments on menhaden larvae.

EFFECTS OF HIGH SALINITY

Equipment and procedures.—Approximately 25 larvae of uniform size, acclimated at 25

to 30‰ salinity, were held in each of six 34-liter polyethylene tanks at salinities of 15, 20, 25, 30, 35, and 40‰. Since larvae transferred directly into water at 35 and 40‰ salinity soon died, tests at these two levels actually were started at 30‰ salinity. The salinity was then gradually raised each day by slowly adding a solution of concentrated sea water until the desired salinities of 35 and 40‰ were reached at the end of a week; no mortality occurred. Salinities were maintained at the test level by the addition of distilled water. Compressed air was used to oxygenate the water and to recirculate it through a filter of charcoal and glass wool. This experiment was started 7 April 1965 and completed 4 June 1965. As in the first experiment, menhaden were fed nauplii of 1- and 2-day-old *Artemia salina*.

Results.—All larvae did not grow at the same rate. Although each tank contained only larvae at the beginning of the experiment, both juvenile and larval forms were present at the end. The differences in size of fish at completion of the experiment may have been due to the consumption of more food by the more aggressive individuals or other unknown metabolic causes. When *Artemia* were introduced, all fish appeared to feed actively, and sufficient *Artemia* were available for all. All the specimens in 20 and 25‰ salinity died during the experiment from unknown causes.

The experiment indicated that larvae will transform into juveniles at higher salinities than are found in most nursery areas. Salinity tolerance of the larvae may be comparable with that demonstrated for herring by Holliday and Blaxter (1960). They showed that eggs and larvae of herring have a wide salinity tolerance and are capable of maintaining the concentration of tissue fluids within relatively narrow limits when subjected to a wide range of salinities.

TABLE 2.—Number of hours to 50% mortality of menhaden larvae acclimated at 15 C and held at different combinations of temperature and salinity

Test temperature Celsius	Salinity ‰						
	0	5	10	15	20	25	30
2	4.5	15.8	46.0	26.8	16.2	14.0	10.2
3	6.0	44.5	53.0	56.0	51.2	27.0	10.5
4	4.5	26.2	> 96.0	> 96.0	> 96.0	39.5	14.0
5	7.2	50.5	> 96.0	> 96.0	> 96.0	> 96.0	48.0
6	8.8	> 96.0	> 96.0	> 96.0	> 96.0	> 96.0	> 96.0

EFFECTS OF SALINITY ON VERTEBRAL DEVELOPMENT

Fish held at salinities of 15, 20, 25, 30, 35, and 40‰ were X-rayed to determine if salinity affected their vertebral development. All vertebral counts fell within the limits described for fish from North Carolina (Sutherland, 1963). Approximately one-third of the specimens in each of the test salinities showed abnormalities (single or double curvature) of the spine. Compression of vertebrae resulted in the bulging of centra in some specimens. These abnormalities, not found in samples of larvae prior to the start of the experiment, may have been partly due to specimens being held in an environment of 15‰ salinity and greater, or to a diet of *Artemia* only. Generally, menhaden are not found in such high salinities in the nursery area until they start their return to the sea as juveniles. The same abnormalities were observed by Bureau biologists in specimens of juvenile *Brevoortia smithi* collected earlier from water of approximately 40‰ salinity in Buttonwood Canal, Flamingo, Florida.

SALINITY-TEMPERATURE RELATION

Results of the two acclimation series in the temperature-salinity experiment indicated that if larvae enter an estuary during the winter or early spring, when water temperatures may approach the freezing point, they will have the best chance of survival if the water temperature does not fall below 4 C and salinity remains between 10 and 20‰. Brawn (1960), testing the survival of herring, *Clupea harengus*, at temperatures between 6 and 9 C, suggested that adverse effects of salinity were minimal at levels above 5‰.

Field observations were made periodically during 1965 to determine what salinities and temperatures are encountered by menhaden larvae in a nursery area. Larvae entered one

such area, Bath Creek, North Carolina, a tidal tributary of the Pamlico River, when the water temperature was approximately 9 C and the salinity less than 5‰. While they were in the area, prolonged rainfall and runoff lowered the salinity to 1‰ or less, and the water temperature rose to 30 C. Pacheco and Grant (1965) studying a tributary of Indian River, Delaware, found larvae at temperatures ranging from 3 to 32 C and salinities of less than 1 to 30‰.

The experiments in which larvae were held at salinities of 15 through 40‰ suggested that larval menhaden can survive and transform into juveniles even if they are forced to remain in a more saline environment than characterizes most nursery areas. Such fish might undergo slight malformation of the vertebral column, but the resulting abnormalities would probably not prevent them from otherwise growing normally. Results also indicate that in these higher salinities some larvae were retarded in growth.

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